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(21)	*Patentansökningsnummer* *Patent application number*	*9903662-6*
(86)	*Ingivningsdatum* *Date of filing*	*1999-10-12*
(30)	*Prioritet begärd från* *Priority claimed from*	*1999-07-30 SE 9902823-5* *1999-09-09 SE 9903226-0*

20 OCT 2000

Stockholm, 2000-10-12

För Patent- och registreringsverket
For the Patent- and Registration Office

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A LIGHT SOURCE, AND A FIELD EMISSION CATHODE.

FIELD OF THE INVENTION

The present invention relates to a light source according to the introductory portion of claim 1, especially a light source for illumination. Further, the present invention relates to a field emission cathode according to the introductory portion of claim 14.

BACKGROUND OF THE INVENTION

One common type of light sources is the fluorescent tube. It has many advantages, but suffers from serious drawbacks. For example, there is always a delay after the power has been turned on until it starts to operate giving full light. It needs complicated control equipment, which requires space. To obtain light with a source of this kind it is unfortunately necessary to use materials having negative environmental effects. It is for example a big disadvantage that mercury has to be used in this type of light sources.

Cathodoluminescent light sources represent another interesting type of light sources. Such light sources, including an evacuated envelope containing a grid and a heated cathode, for emission of electrons, are known from GB, A, 2 070 849 (The General Electric Company Limited), GB, A, 2 097 181 (The General Electric Company PLC), GB, A, 2 126 006 (The General Electric Company plc) and GB, A, 2 089 561 (The General Electric Company Limited). The insides of the envelopes are covered with a layer of phosphor of an electron-responsive type. These cathodoluminescent lamps have essentially the form of an electric bulb.

Since these light sources all have a heated cathode, the cathode has to be heated by special means, before the emission of light starts.

The use of electrons exciting phosphor to luminescence has the effect that more heat is produced than in comparable fluorescent tubes. It is therefore advantageous if the active surface, for the emission of light and for the necessary heat dissipation, is large. The cathodoluminescent lamps shown in the documents mentioned do not have optimal surfaces.

To overcome the drawbacks and problems with the fluorescent tubes and cathodoluminescent light sources, light sources having field emission cathodes were developed.

A light source of this kind is disclosed in US, A, 5 588 893 (Kentucky Research and Investment Company Limited). A field emission cathode is arranged inside an evacuated glass container having a luminescent layer arranged on its inner surface. A modulator or extraction electrode is provided between the cathode and the luminescent layer. The cathode includes carbon fibres, arranged in bundles, preferably in a matrix, on a substrate. The content of US, A, 5 588 893 is incorporated herein by reference.

However in the last-mentioned known light source, electrons are emitted only in a direction perpendicular to the substrate. Also, there is no indication in the document how to produce the light source in a cost-efficient way.

The above mentioned US, A, 5 588 893 (Kentucky Research and Investment Company Limited) also discloses a field emission cathode of the kind mentioned above. The cathode disclosed includes carbon fibres, arranged in bundles, preferably in a matrix, on a substrate. The document also discloses a method

including treatment of the emitting surfaces in order to achieve a cathode with higher efficiency than previous cathodes.

Further, WO,A1,98/57344 (LightLab AB) and WO,A1,98/57345 (LightLab AB) disclose light sources having cylindrical geometry and employing field emission. In order to obtain the necessary electric field for field emission, the mentioned light sources include grids or modulator electrodes arranged close to the field emitting surfaces of the cathodes. In those light sources a relatively high electric field has to be created between the cathode and the grid, and the distance between the field emitting surfaces and the grid has to be small and uniform in order to achieve a sufficient electric field for field emission and good distribution of electrons emitted from the cathode.

A further document, WO, A1, 97/07531 (Silzars et. al.) discloses a lighting apparatus including a field emission cathode. The cathode is built up of one or more fibers. The fibers are very thin, having a diameter less than 100 microns, and preferably less than 10 microns. The diameters are selected in order to achieve field emission at reasonable voltages. A construction according to this document having one fiber will be inoperative if the fiber is broken. Since the fiber is very thin, the probability of that it breaks appears to be high. However, the probability is probably somewhat lowered by arranging more than one fiber in parallel, for redundancy. Moreover, the electron emission surface is very small due to the small diameter of the fiber(s).

Previously known field emission cathodes are often of a complicated and fragile construction, especially as concerns the mountings and the attachment of field emitting bodies.

It has been found in connection with cathodes including standard carbon fibers and a grid that the electrical fields acting between the cathode and a grid or an anode can cause individual fibers to get loose from their carrier if they are not safely secured thereto. Once loose, the fibers will, in most cases, be attracted by the grid and cause a short circuit between the cathode and the grid, until it burns off after some time due to the resulting current through the fibres.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a light source and a field emission cathode, respectively, providing a concentrated electric field at the field emission surface(s), and by which at least some of the drawbacks above are eliminated or reduced.

These and other objects are attained by the features set forth in the appended independent claims.

By the features in claims 1 and 14, it is achieved a light source and a field emission cathode, respectively, having a long life, with high efficiency and stability, which can be produced at low cost.

By the features in claims 1 and 14, it is achieved a light source and a field emission cathode, respectively, having a sufficient electric field for field emission with good distribution and high emission of electrons from the cathode.

By the features in claims 1 and 14, it is also achieved a light source and a field emission cathode, respectively, in which field emission can be obtained without the use of a grid or extraction electrode.

By the features in claim 1, further, a light source without a starting up period is achieved, i.e. when the power is turned on, the light starts immediately, thanks to the use of a field emission cathode. A light source with no need for materials having negative environmental effects is also achieved.

By the features in claim 1, further, a light source having a field emitting cathode of simple and robust construction is obtained.

Further, by the features in claim 5, a light source having a suffficiently large active light emitting surface is achieved. This efficient use of the surface renders it possible to achieve a light source having a high light emission in relation to the heat produced.

By the features in claim 14, further, a field emitting cathode of simple and robust construction is obtained.

By the features in claims 14 through 21, a field emitting cathode is obtained which further provides for a high emission and uniform distribution of emitted electrons, in particular through a spherical region surrounding the cathode.

Further features and advantages will be apparent from the dependent claims and the detailed description below.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows schematically a longitudinal section of an embodiment of a light source according to the present invention,

Fig. 2 shows schematically the cathode and the anode as disclosed in Fig. 1,

Fig. 3 shows schematically a longitudinal section of an alternative embodiment of a light source according to the present invention, and

Fig. 4 shows schematically a longitudinal section of a further alternative embodiment of a light source according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to figure 1, there is shown, in a schematic longitudinal section, an embodiment of a light source according to the present invention, identified generally by the numeral 10, and especially intended for illumination purposes. It includes a container having walls, one of which is identified by the numeral 20. This wall 20 has an outer glass structure and is shown to be spherical. The sphere 20 has an end 21 which is covered by an end cap 60. A sealing (not shown) is provided between the end cap and the sphere 20, in order to achieve an air-tight sealing of the container. The container is sealed in order to maintain the vacuum (approximately 10^{-6} torr) created when the container is evacuated.

Inside the container and preferably centrically therewith, a cathode 40 is arranged. This cathode is a cold cathode, especially a field emission cathode. Its construction and function will be explained further below.

The light source is provided with electrical connections 51, 52, and means 70 for supporting of the cathode 40. The cathode 40 is held in place by a thin conducting rod 70 extending to

the end cap 60. The rod 70 could be clamped to the cap 60 by clamping means or gripped by gripping means.

The spherical part 20 of the container walls surrounding the cathode 40 consists of an outer glass structure 23, a phosphor layer 24 (a cathodoluminescent phosphor) and an inner conductive layer 25 forming an anode. The phosphor layer is a luminescent layer which upon electron bombardment emits visible light. The anode is preferably made of a reflecting, electrically conductive material, e.g. aluminum. By arranging an aluminum layer covering the phosphor layer, adverse effects on the vacuum by possible evaporation of the phosphor are avoided.

The electrical connection means 51, 52 connect the cathode 40 and the anode 25, respectively, to a feed circuit (not shown). Those connection means preferably include conductive terminal pins which extend through the cap 60 and are insulated from each other. The electrical connection means 52 could further include conductive fingers or similar, which are in contact with the anode layer 25 provided inside the container. The openings for the electrical connection means 51, 52 in the end cap 60 are air-tight sealed.

The cathode 40 includes a relatively small sphere of electrically conductive, electrically semi-conductive or insulating material, e.g. of nickel. The radius thereof is in the millimeter range, about one to ten mm. This provides for a strong and durable cathode, exhibiting a surface sufficient for a high emission of electrons.

In operation, a DC voltage is supplied between the cathode 40 and the anode 25 by means of the mentioned feed circuit (not shown), which could be located in a housing, connected to the

AC mains e.g. through an ordinary lamp socket. The feed circuit supplies the voltages to the conductive terminal connections 51-52, to which it is connected. Preferably connection 52 is at ground potential and connection 51 is negative. When the voltage is applied, an electrical field is created between the cathode 40 and the anode 25.

Due to the geometry of the light source according to the invention a favourable distribution of the electric field is obtained. The electric field is strongest where a strong electric field is needed, for obtaining field emission, namely around the cathode. The following formula gives the electric field strength in a structure according the invention, having a central spherical cathode surrounded by a spherical conductor as an anode:

$\mathbf{E(R_i)} = \frac{R_0}{R_i} \cdot \frac{V_0}{R_0 - R_i}$, where $E(R_i)$ is the electric field strength at the central sphere, V_0 is the voltage applied between the two spheres, R_i is the radius of the inner sphere (the cathode) and R_o is the inner radius of the outer sphere(the anode). In Figure 2, which schematically shows the cathode and the anode of Figure 1, the variables of the formula are indicated. As seen from the formula a very strong electric field close to the cathode can be obtained with suitably selected dimensions. Especially a small radius of the cathode (small R_i) will give a high electric field close to the cathode. The electric field lines will be concentrated around the cathode, and it can be seen as if the cathode were surrounded by a virtual extraction electrode.

In order to obtain field emission from the cathode, it is covered with a field emitting material, such as a layer of carbon nanotubes. The electric field is then further amplified around the field emitting tips, and an amplification factor (of the field) of 1000 and even more can be obtained. This can

be seen as an amplification of the effect of said virtual extraction electrode. Taking this amplification factor (about 1000) into account, the electric field needed to efficiently extract electrons (by field emission) from a layer of nanotubes is about 1 kV/mm.

For further explanation and discussion of nanotubes it is referred to the articles "Field emission from carbon nanotubes: a comparative study" by J M Bonard, J P Salvetat, T Stöckli, L Forró, A Châtelain, Proceedings of the 193rd ECS sumposium,1998, and "Field emission properties of multiwalled carbon nanotubes" by J M Bonard, F Maier, T Stöckli, A Châtelain, W A de Heer, J P Salvetat, L Forró, Ultramicroscopy 73 (1998) 7-15, which articles are incorporated herein by reference.

The irregularities are formed by carbon nanotubes applied on the surface of the spherical cathode. The nanotubes have a very short length, less than about 10 μm, and do not affect the variable R_i the formula since the radius of the sphere is selected in the mm range, about one to ten mm. The tips of the nanotubes have a radius of curvature being in the range 0.1-100 nanometers.

The applied carbon nanotubes can be of different types, e.g. single wall nanotubes or open or closed multi wall nanotubes. In this case catalytically deposited multi wall nanotubes deposited in the form of a film are suitable and can be applied by a simple process. Such nanotubes are suitable for depositing on a sphere and they will be appropriately oriented by the process, with their respective longitudinal axis being essentially perpendicular to the surface of the sphere. Further, application of nanotubes by a catalytic or alternatively CVD process results in good uniformity and low manufacturing cost. Recent laboratory measurements confirm

The above calculations are given as examples for a perfect spherical symmetry. In reality one must of course take into consideration the fact that the central sphere is held in place by a thin conducting rod and that the outer sphere has an extension to the socket (compare Figs. 1, 3 and 4).

Additionally, one can also consider cases where not the whole surface of the inner sphere is covered with phosphos, as is disclosed in the embodiment of Fig. 3.

Furthermore it is also possible to move the inner sphere to a non-central position in the outer sphere in order to increase the light intensity in certain directions. This follows from the embodiment disclosed in Fig. 4.

Due to the geometry of the light source according to the invention, the dimensional tolerances are not required to be very exact, especially in comparison to light sources having a grid. This is apparent from the formula above, and contributes to low manufacturing costs.

According to an alternative arrangement, not disclosed on the drawing, the glass sphere could be covered, on at least a major part of its inside, by an electrically conductive transparent material forming the anode. The anode then carries a phosphor layer on the inside. The anode is made from e. g. indium-tin-oxide or indium oxide. To establish direct electrical contact with the anode conductive fingers can be arranged as mentioned above and some regions of the anode are therefore not covered with phosphor. Alternatively, electrically conductive surfaces being in contact with the anode can be applied on to the phosphor layer. Those surfaces are small not to interfere with the operation of the light

CLAIMS

1. A light source, comprising an evacuated container having walls, at least a portion of which comprises an outer glass structure (23) which on at least part thereof is coated on the inside with a layer of phosphor (24) forming a luminescent layer, and a conductive layer (25) forming an anode, which layer of phosphor (24) is excited to luminescence by electron bombardment from a field emission cathode (40) located in the interior of the container,
characterized in that
- the field emission cathode (40) comprises a carrier, at least partly taking the form of a sphere, and
- at least a portion of the surface of said sphere being provided with conductive surface irregularities in the form of tips, having a radial extension being less than about 10 μm.

2. The light source according to claim 1, wherein said carrier is made of a conductive material.

3. The light source according to claim 1, wherein said carrier is made of a semi-conductive material.

4. The light source according to claim 1, wherein said carrier is made of an insulating material.

5. The light source according to any of claims 1-4, wherein the container at least partly takes the form of a sphere having a radius within the range of 1-10 cm

6. The light source according to any of claims 1-5, wherein the carrier is arranged in the center of the container.

7. The light source according to any of claims 1-5, wherein the carrier is eccentrically arranged in the container.

8. The light source according to any of claims 1-7, wherein
- the tips have a radius of curvature being in the range 0.1-100 nanometers.

9. The light source according to any of claims 1-8, wherein
- the surface of said carrier is at least partially covered with carbon nanotubes, each having a longitudinal axis being essentially perpendicular to the surface of the carrier, and
- the free ends of said nanotubes constitute said tips.

10. The light source according to any of claims 1-9, wherein the tips are essentially uniformly distributed on said portion of the surface of said sphere being provided with surface irregularities.

11. The light source according to any of claims 1-10, wherein
- the luminescent layer (24) is arranged between the glass structure (23) and the anode (25), and
- the anode (25) is made of a reflective material for reflection of the light emitted from the luminescent layer (24).

12. The light source according to any of claims 1-11, wherein
- the anode is arranged between the glass structure and the luminescent layer, and
- the anode is made of a transparent material.

13. The light source according to any of claims 1-12, wherein
- the phosphor layer is formed by a conductive phosphor

and the phosphor layer also forms the anode.

14. A field emission cathode (40), for use in a light source, and to be at least partially encompassed by an anode, and comprising further means,
characterized in that
- said further means includes conductive surface irregularities in the form of tips, having a radial extension being less than about 10 µm , and being provided on at least a portion of a carrier including a spherical surface.

15. The light source according to claim 14, wherein said carrier is made of a conductive material.

16. The light source according to claim 14, wherein said carrier is made of a semi-conductive material.

17. The light source according to claim 14, wherein said carrier is made of an insulating material.

18. The field emission cathode (40) according to any of claims 14-17, wherein
- the cathode is to be at least partially encompassed by an anode at least partly taking the form of a sphere having a radius within the range of 1-10 cm.

19. The field emission cathode according to any of claims 14-18, wherein
- the tips have a radius of curvature being in the range 0.1-100 nanometers.

20. The field emission cathode according to any of claims 14-19, wherein

ABSTRACT

A light source including a field emission cathode and a field emission cathode.

- The light source, comprises an evacuated container having walls, including an outer glass structure (23) which on at least part thereof is coated on the inside with a layer of phosphor (24) forming a luminescent layer and a conductive layer (25) forming an anode. The phosphor (24) is excited to luminescence by electron bombardment from a field emission cathode (40) located in the interior of the container. The field emission cathode (40) comprises a carrier, at least partly taking the form of a sphere, and
- at least a portion of the surface of said sphere being provided with conductive surface irregularities in the form of tips, having a radial extension being less than about 10 µm.

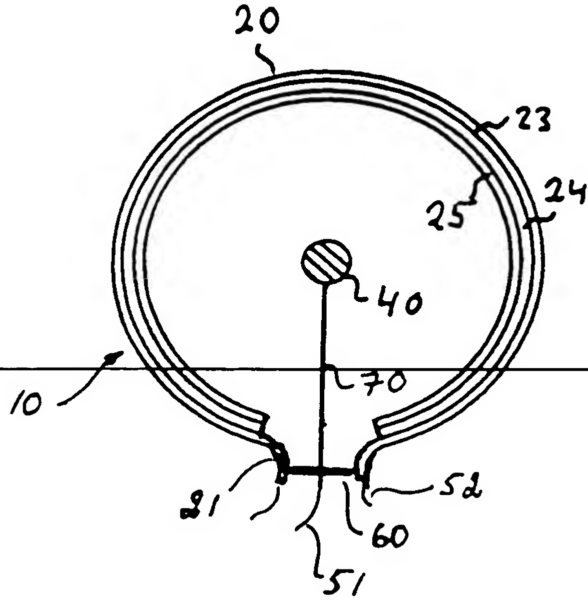

Fig. 1

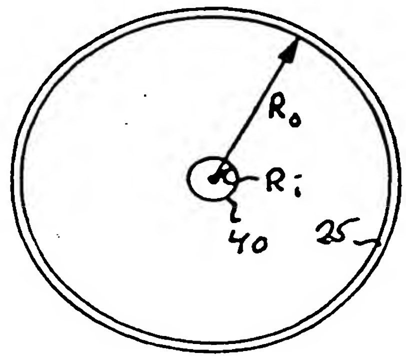

Fig. 2

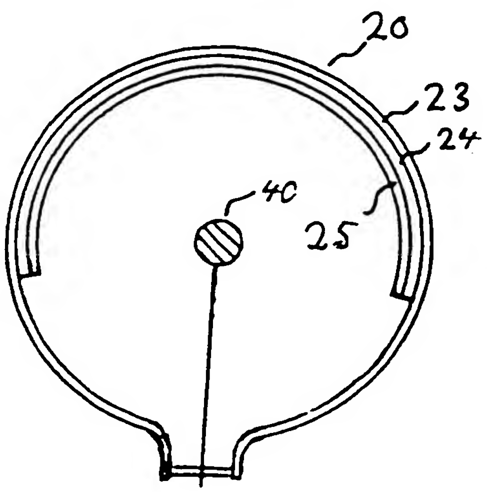

Fig. 3

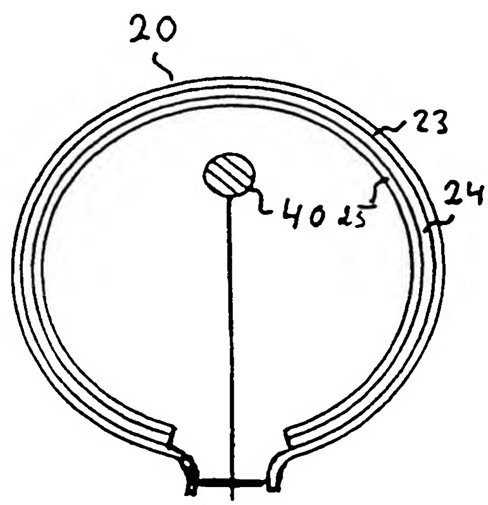

Fig. 4